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DIVISION S-8—FERTILIZER TECHNOLOGY AND USE

Performance of Sulfur-Coated Urea Under Intermittently Flooded Rice Culture in Peru[1]

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ABSTRACT

Short-statured, high yielding rice (*Oryza sativa* L.) varieties grown extensively in northern Peru require extremely high rates of conventional N sources to achieve maximum yields. The recovery of applied N is extremely low due to the use of intermittent flooding. This water management system results in heavy N losses even with properly timed split applications. In search of simpler and more efficient methods of N management, eight field experiments were conducted in the region to evaluate sulfur-coated urea (SCU), an experimental, slow-release N source supplied by the Tennessee Valley Authority. Rice yields were increased an average of 59% more by pretransplant-incorporated SCU than by urea or ammonium sulfate applied in the same manner. SCU produced an average of 20% higher grain yield response than topdressed applications of urea or ammonium sulfate. SCU applications increased panicle production, N uptake at harvest; and the apparent recovery of added N. Beneficial effects of SCU were more pronounced in sites where check yields were low, especially less than about 4.8 ton/ha. In sites with high N supplying capacity, SCU produced excessive vegetative growth which resulted in yield reductions at high N rates.

Regardless of an assumed 48%-higher unit N cost in SCU, the overall benefits of pretransplant-incorporated applications of SCU were favorable since there was a decrease of 40% in the optimum rate of N and the need for precise timing of application was eliminated.

Additional Index Words: slow-release fertilizer sources, nitrogen fertilizer efficiency.

IN MOST RICE GROWING AREAS of the tropics, intermittent flooding is the predominant form of water management (8). Constant flooding during the growing season is difficult to maintain in many areas because of the variability in rainfall distribution or the limitations in existing irrigation systems. Large losses of added nitrogen take place under alternate flooding and drying due to leaching and denitrification of recently oxidized nitrate ions (4). Low recovery of added N is one of the main factors limiting profitable rice (*Oruza Sativa* L.) production in Peru, where high yielding, short-statured varieties are extensively grown under intermittent flooding. With these varieties, optimum grain yields of 6 to 12 tons/ha are obtained with N applications rates of 200 to 400 kg N/ha (6).

Previous work has shown that single applications of urea or ammonium sulfate incorporated in the topsoil prior to transplanting are very inefficient when compared to split applications topdressed at tillering and panicle initiation (6, 8). The latter practice results in an apparent N recovery of 20 to 30%, which is still quite low when compared to the 40 to 50% recovery commonly attained with constant flooding (5, 9). Previous work showing no significant difference between urea and ammonium sulfate as N sources is considered evidence of the absence of either deficiency or response to S by rice grown in the Coast of Peru (2, 6).

In our search for simpler and more efficient N management practices, arrangements were made with the Tennessee Valley Authority to test the effectiveness of sulfur-coated urea (SCU), an experimental slow-release N source. The purpose of this study was to determine whether SCU applications are more efficient than applications of conventional N sources in intermittently flooded rice culture.

EXPERIMENTAL PROCEDURE

Eight field experiments were conducted in the Lambayeque, Jequetepeque, and Bagua Valleys of northern Peru from 1969 to 1972. The climatic characteristics of these arid areas have been described elsewhere (7). The soils are derived from calcareous alluvium and are relatively uniform morphologically. In the eight experiments, topsoil texture ranged from clay loam to clay, pH from 7.9 to 8.3, and organic matter from 1.6 to 2.0%. The dominant clay mineral is montmorillonite. No responses to nutrients other than N have been recorded for rice in these areas (2, 6).

All experiments had a split-plot design with three or four replications. The main plots consisted of N rates varying from 0 to 400 kg N/ha at 80 kg increments, except in Exp. 5 and 6 as indicated in Fig. 1. The subplots consisted of the following source-time combinations:

1. SCU-b: Sulfur-coated urea with dissolution rates of 0.6 to 2.2% N per day; 33 to 37% N, and 10 to 21% S (1). SCU was incorporated into the topsoil immediately before transplanting; hereinafter referred to as the basal application.
2. Urea-b: Commercial urea (46% N), applied as in treatment 1.
3. Urea-t: Commercial urea (46% N), topdressed application half at tillering and half at panicle initiation; broadcast on a thin layer of standing water.
4. AS-b: Commercial ammonium sulfate (21% N, 25% S), applied as in treatment 1. (Only in Exp. 2, 5, and 7.)
5. AS-t: Commercial ammonium sulfate (21% N, 24% S) topdressed application like in treatment 3. (Only in Exp. 5 and 7.)

The following short-statured, high yielding rice varieties were used: 'IR5' in Exp. 1, 'IR8' in Exp. 2, 3, 4, 6, 8, and 'Naylamp' ('IR930-2-6') in 5 and 9. These varieties are very similar in

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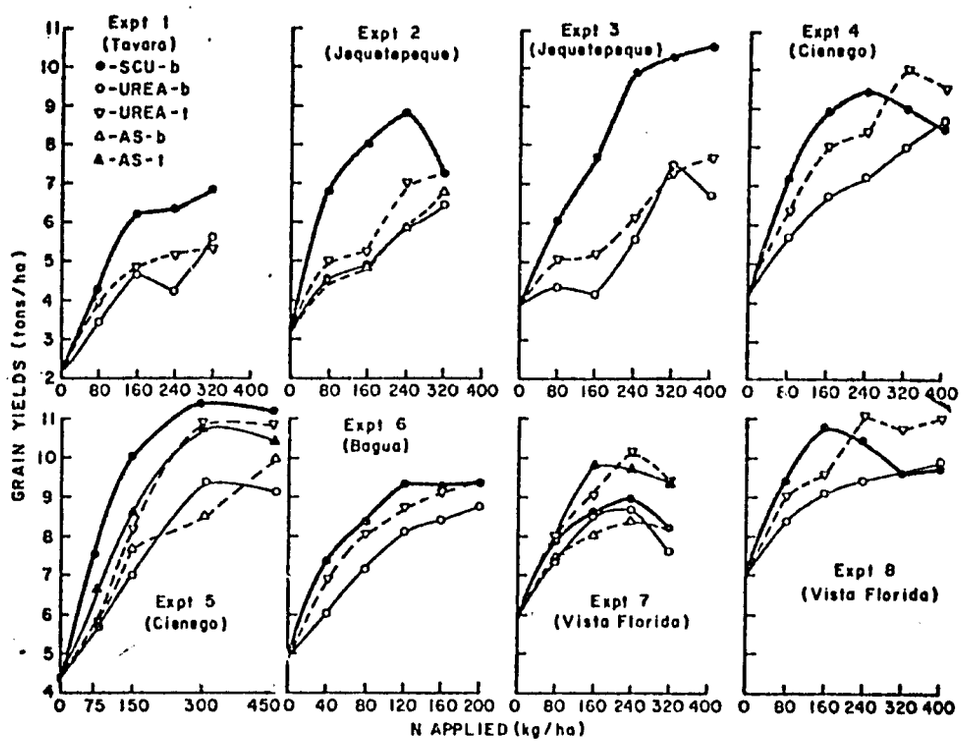

Fig. 1—Yield response by rice of different N source-time combinations.

Table 1—Grain yield response to various source-time combinations by individual experiments (mean of N rates)

Exp. no.	Yield with no applied N	Mean response SCU-b	Urea-b	Urea-t	AS-b	AS-t	LSD 0.05
	ton/ha						
1	2.21	3.66	2.59	2.28	--	--	0.51
2	3.26	4.45	2.19	2.90	2.24	--	0.54
3	3.88	5.04	1.83	2.75	--	--	0.57
4	4.19	4.47	3.12	4.33	--	--	0.36
5	4.40	5.65	3.41	4.50	3.61	4.75	0.51
6	4.82	3.72	2.86	3.61	--	--	0.30
7	5.88	2.53	2.16	3.27	2.16	3.35	0.55
8	7.03	2.97	2.27	3.30	--	--	0.39
Mean	4.45	4.06	2.55	3.37	--	--	--

their yield and nitrogen response pattern and differ mainly in disease resistance and grain quality. Rice seedlings were grown from 35 to 65 days in ordinary seedbeds and were transplanted in 15 m² subplots in hills spaced at 25 by 25 cm. The experiments were flood-irrigated whenever water was available. Intervals between floodings ranged from 8 to 12 days. Weeds were satisfactorily controlled and no significant pest or disease attacks were observed. Plant height, tillering, dry matter production, and N uptake were determined at 30 days after transplanting, at panicle initiation, at 50% flowering, and at harvest. Grain yields were determined in a 5 m² central area devoid of border effects and adjusted to 14% moisture. Yield components were determined in one hill randomly chosen at harvest. Apparent N recovery was calculated by the uptake differences from the check plots located in each main plot. Regression equations for each source-time combination were used to calculate the optimum economic yield and N rate, based on the first derivative and the 1972 cost-price ratios.

RESULTS AND DISCUSSION

Yield Responses

The main effects of the source and time treatments are shown in Table 1 in which the experiments are arranged in order of increasing grain yields without added N. No significant differences were observed between urea and ammonium sulfate sources in the experiments where this comparison was made. Topdressed applications of urea or ammonium sulfate were significantly superior to basal applications of these sources in all but one experiment. These results confirm previous observations about the similar performance of these carriers and the superiority of properly timed topdressed applications over a basal dose.

SCU-b produced a significantly higher yield response than basal applications of urea or ammonium sulfate in all but one experiment in which the difference was not large enough to be significant. The average yield response of SCU-b was 4.06 ton/ha or 59% higher than the average yield response of basal urea applications (2.55 ton/ha).

SCU-b was significantly superior to topdressed applications of the conventional sources in four experiments, not significantly different in three, and significantly inferior in one (Table 1). As the check plot yields increased, the superiority of SCU-b over the topdressed conventional sources declined. The overall yield response of SCU was 20% higher than that of the topdressed urea (3.37 ton/ha).

The interaction between N source-time combinations and N rates was significant in all cases. Yield response curves are shown in Fig. 1. In all experiments, SCU-b outyielded at all N levels basal applications of urea or ammonium sulfate. SCU produced a clearly superior response in Exp. 1 to 4 in which the yields without added N were lower and where the alternate wetting and drying cycles were more pronounced. In Exp. 4, 5, 6, and 8, SCU-b produced a more marked yield response than topdressed applications of urea or ammonium sulfate. Although the maximum yields obtained with each source did not vary significantly in these experiments, the crops required a lower N

Table 2—Effects of source-time combinations on plant characteristics and nitrogen relations in Exp. 1

Source and time	Rate	Grain/straw ratio	Panicles	N at harvest	N uptake	Recovery of added N
	kg N/ha		per m²	%	kg N/ha	%
Check	0	1.12	193	0.73	31	--
SCU-b	80	1.21	297	0.88	69	48
	160	1.58	365	0.91	91	38
	240	1.67	394	1.01	102	30
	320	1.81	467	1.18	126	30
	Mean	1.57	381	1.00	97	36
Urea-t	80	0.95	247	0.75	53	28
	160	1.11	285	0.81	72	26
	240	1.41	261	0.79	57	11
	320	1.69	288	0.86	77	14
	Mean	1.29	270	0.80	65	20
Urea-b	80	1.34	328	0.80	55	31
	160	1.42	345	0.75	61	19
	240	1.71	361	1.05	86	23
	320	1.81	398	1.02	83	17
	Mean	1.57	358	0.91	71	22

rate as SCU to attain maximum yields. In Exp. 7, topdressed applications of urea and ammonium sulfate produced significantly higher maximum yields than basal SCU at about the same N rate.

Additional data (not shown) indicate that a single topdressed SCU application at the tillering stage was as effective as SCU-b.

Besides the lower N rates required with SCU-b, an additional practical advantage of this source is the elimination of the precise timing necessary when conventional N sources are topdressed at the panicle initiation stage.

Plant Characteristics

In order to explore further the nature of the response differences in sites with low and high yield levels without added N, several crop parameters were determined and the results for Exp. 1 and 8 are shown in Tables 2 and 3, respectively. In terms of grain yields, SCU was overwhelmingly superior to the conventional sources at all N rates in Exp. 1, while SCU approached the maximum yield at a lower N rate than topdressed urea in Exp. 8.

The grain/straw ratio of the dry matter at harvest is a good indicator of the effectiveness of N use for grain production. In Exp. 1, grain/straw ratios increased with increasing N rates with little difference between sources, indicating severe N deficiency and more marked responses. In Exp. 8 grain/straw ratios decreased with increasing N rates, suggesting a high initial N supply in the soil. The sharp decrease in grain/straw ratios at high SCU rates reflects the negative yield response observed and indicates excessive vegetative growth caused by too much available N.

The number of panicles per unit area is the yield component most closely correlated with yield responses in short-statured rice varieties (8). In both experiments, SCU applications produced more panicles per m² than conventional urea, suggesting that the slow-release source encourages the production and maintenance of more tillers than the completely soluble sources. Extremely high panicle production levels are usually accompanied by decreases in filled grains per panicle and grain yields in transplanted rice (3). This may also account for the yield decreases obtained with 320 and 400 kg N/ha as SCU in Exp. 8. (Fig. 1). Possibly the same conditions are reflected in Exp. 2, 4, and 7.

Table 3—Effects of source-time combinations on plant characteristics and nitrogen relations in Exp. 8

Source and time	N rate	Grain/straw ratio	Panicles	N at harvest	N uptake	Recovery of added N
	kg N/ha		per m²	%	kg N/ha	%
Check	0	1.68	266	0.93	108	--
SCU-b	80	1.46	327	0.91	151	54
	160	1.44	383	0.97	175	42
	240	1.41	418	1.10	192	35
	320	1.12	480	1.08	223	36
	400	1.02	464	1.20	226	30
	Mean	1.29	414	1.05	193	39
Urea-t	80	1.58	268	0.96	177	24
	160	1.81	333	0.93	147	24
	240	1.55	411	1.07	199	38
	320	1.46	424	1.11	206	31
	400	1.52	429	1.10	202	24
	Mean	1.58	373	1.03	176	28
Urea-b	80	1.44	298	0.91	137	36
	160	1.45	285	0.96	143	22
	240	1.27	344	0.91	179	30
	320	1.12	434	0.96	179	22
	400	1.18	451	1.09	198	22
	Mean	1.29	362	0.97	167	26

Table 4—Optimum N application rates and grain yields of source-time combinations calculated from yield regression equations

Exp. no.	N rate					Optimum grain yields				
	SCU-b	Urea-b	Urea-t	AS-b	AS-t	SCU-b	Urea-b	Urea-t	AS-b	AS-t
	kg N/ha					ton/ha				
1	266	248	480	--	--	6.72	5.31	5.58	--	--
2	201	426	469	417	--	8.62	7.10	8.10	6.06	--
3	372	*	*	--	--	10.63	*	*	--	--
4	258	521	532	--	--	9.80	9.21	11.16	--	--
5	290	374	388	478	434	11.74	9.33	11.05	10.06	10.92
6	147	206	174	--	--	9.50	8.77	9.32	--	--
7	186	189	234	216	217	9.18	8.60	9.42	8.43	9.90
8	222	301	303	--	--	10.78	10.57	11.09	--	--
Mean	224	323	369	--	--	9.47	8.41	9.38	--	--

Prices: Rough rice: $0.11/kg; Urea: $0.21/kg N; Ammonium sulfate: $0.29/kg N; Sulfur-coated urea: $0.34/kg N

* No quadratic term.

Nitrogen Parameters

Tables 2 and 3 show that the soil supplied up to 31 kg N/ha to the rice crop in Exp. 1 and as much as 108 kg N/ha in Exp. 8. The N content of the above-ground plant parts and the N uptake at harvest were higher with SCU applications in both experiments. At high rates of SCU in Exp. 8, the total N uptake was substantially above the level considered optimum for the site and variety, 180 kg N/ha, according to data from a concurrent study.

The apparent recovery of added N, calculated by uptake differences show that SCU was a more efficient source in both experiments, with an average recovery range of 36 to 39% and maximum recovery values of 48 to 54%. Commercial urea averaged from 20 to 38% recovery with highest values of 31 and 38% (Tables 2 and 3). Although the recovery values at harvest are similar for basal and split applications of commercial urea, the superior behavior of split applications is related to a higher percent N contents in the plants at the critical stages of tillering and panicle initiation. Basal applications of urea tended to have a lower percent N content at panicle initiation.

Economic Interpretation

The optimum rate for each source-time combination appears in Table 4 along with the economically optimum grain yield levels. These calculations are based on 1972

prices of rough rice, urea, and ammonium sulfate in Peru and the assumption that the unit cost of SCU is 48% higher than commercial urea, as suggested by TVA personnel. (More recent (December, 1972) TVA estimates based on larger scale production suggests that the unit cost of SCU is 32% higher than commercial urea.) Quadratic regression equations accounted for 65 to 95% of the variation in yields as indicated by the R^2 values obtained. Optimum rate calculations were not possible for two treatments in Exp. 3, as only the linear term in the equation was significant. SCU-b produced average optimum yields almost identical to those of topdressed urea, but the optimum N rate required to reach the optimum yield was about 40% less with SCU-b than with topdressed urea (224 vs. 369 kg N/ha). In many experiments the difference was substantially wider. Even in the sites with high yields without added N, the N rate required to reach the optimum economic yields was substantially lower with SCU-b.

CONCLUSIONS

This study shows that basal applications of sulfur-coated urea are more efficient than basal or topdressed applications of urea or ammonium sulfate in intermittently flooded rice culture in northern Peru. The lack of differences between urea and ammonium sulfate and the superiority of SCU over these sources as basal applications indicate that the beneficial effect of SCU is related to its slow-release properties in an environment conducive to high losses of applied N. Plant growth and N parameters indicate that SCU is indeed more efficient in supplying N to the rice plant and that N uptake could become excessive and even reduce yields at high rates of SCU applications.

These results have been obtained with high yielding, lodging-resistant varieties, and cannot be directly extrapolated to tall, traditional rice varieties, or to conditions of constant flooding.

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